Systematic studies of freeze-out source size in relativistic heavy-ion collisions by RHIC-PHENIX

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PHENIX

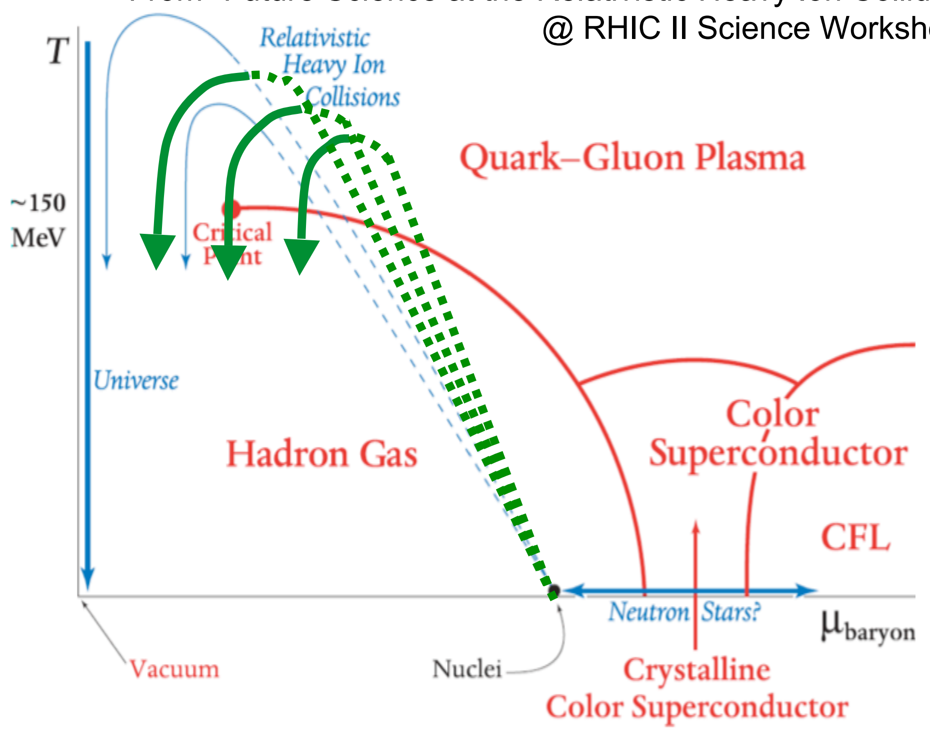
Physics & Advanced Technologies

Outline

- Physics motivations
- Introduction of HBT analysis
- Hadron PID by PHENIX detector
- Centrality dependence of 3-D HBT radii
  - Comparison between different collision energy, species
  - A scaling property of HBT radii
- Momentum dependence of 3-D HBT radii
  - Comparison between different collision energy, species
  - Comparison between different PID hadrons
- Source function by 1-D HBT-imaging analysis
  - What have we learned from the imaged source function?
- Summary

Physics interest of relativistic heavy-ion collisions

From "Future Science at the Relativistic Heavy Ion Collider" @ RHIC II Science Workshops

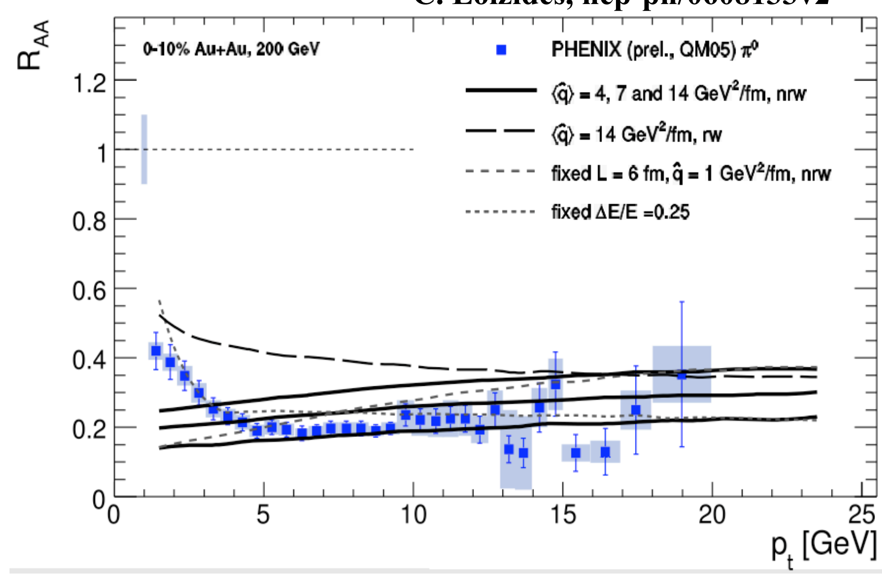


How fast the extremely hot and dense matter thermalizes and freezes-out, how much the system size grows, what is the nature of the phase transition that occurs?

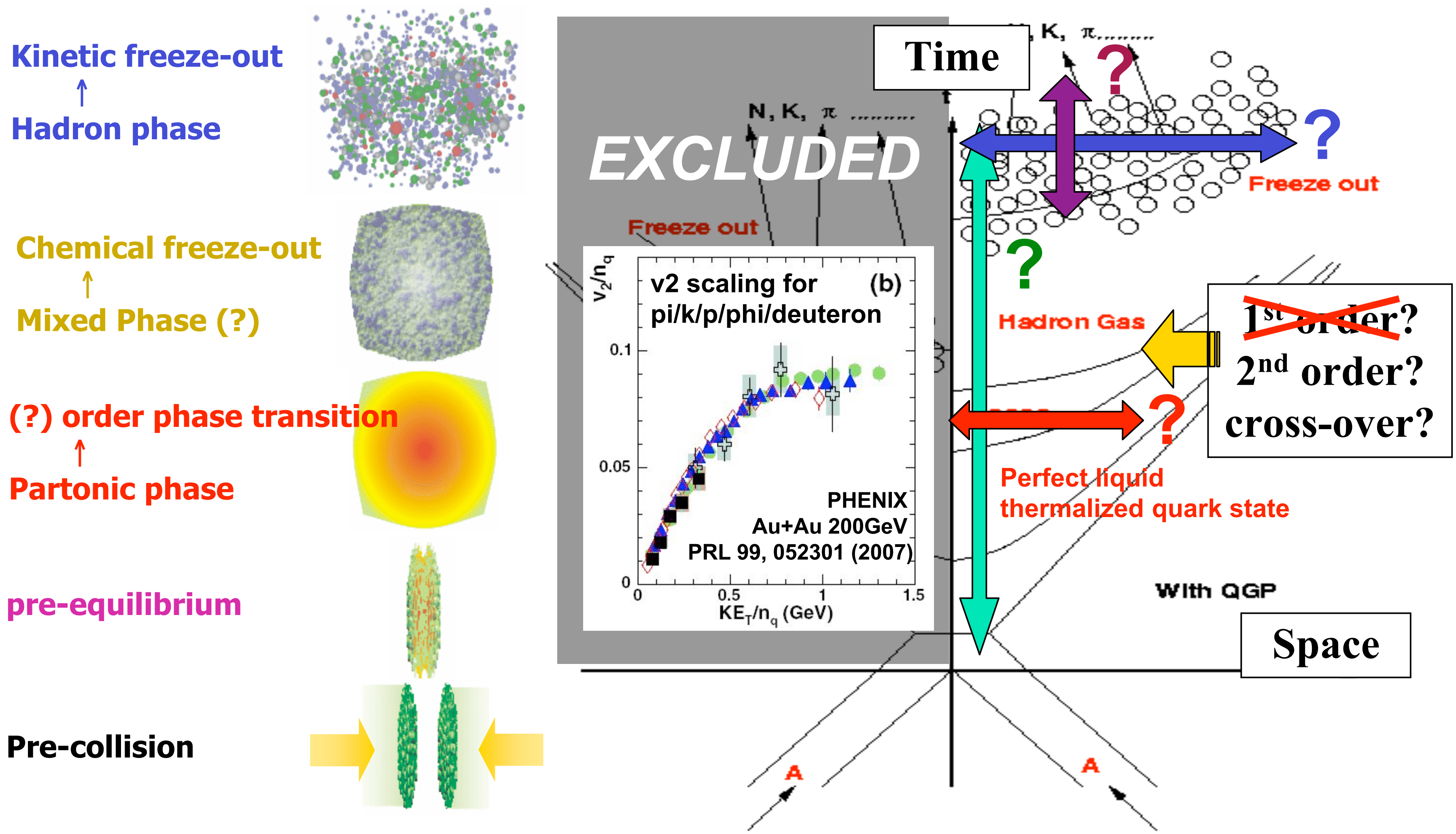
RHIC experiments and following many theoretical efforts (e.g hydrodynamics model) have been very successful in investigating and describing the QGP state (hard observables) quantitatively:

- how hot and dense the matter is
- how opaque the matter is against jets
- how strongly the matter is coupled
- quark level thermalization
- almost perfect fluid (η/s<<1)

C. Loizides, hep-ph/0608133v2

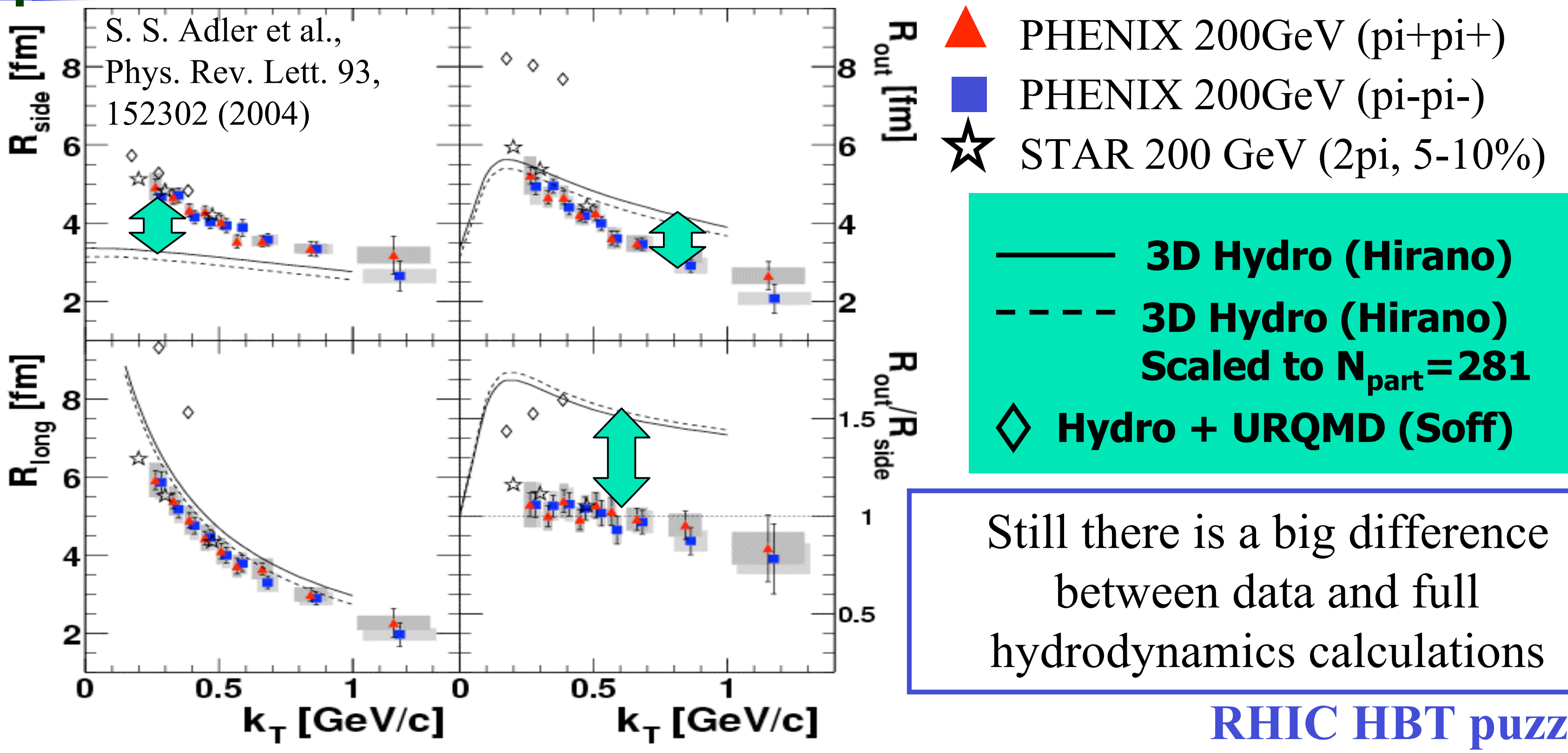


Physics interest of HBT analysis



Detailed characteristics and properties of the space-time evolution can be studies by systematically measuring HBT parameters for different collision energies, collision species, PIDs …

5 What does the RHIC-HBT puzzle mean?



Still there is a big difference between data and full hydrodynamics calculations

RHIC HBT puzzle?

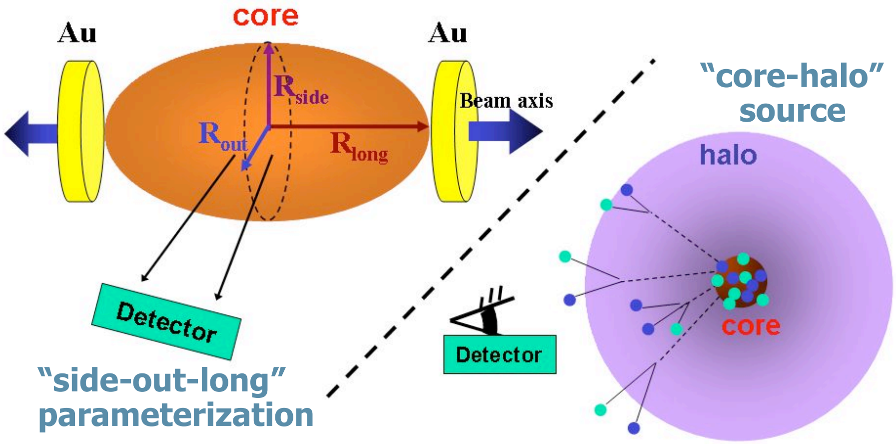
Dynamical x-p correlation is hard to calculate, and a problem is "indirect" and "inconsistent" comparison of fitted HBT radii:

- Do ad hoc corrections for FSI (e.g. Coulomb effect).
- Fit to correlation in a assumption of Gaussian shape.
- ***Even comparisons between experimental results are done with different Coulomb corrections, Gaussian assumptions, rapidity acceptances…***

6 *Two approaches to emission source function*

Classical

3-D Gaussian parameterization with core-halo model



$$C_2 = C_2^{\mathrm{core}} + C_2^{\mathrm{halo}} = \left[(1+G)\lambda\right]F_C + \left[1-\lambda\right]$$

$$G = \exp\left(-R_{\mathrm{side}}^2 q_{\mathrm{side}}^2 - R_{\mathrm{out}}^2 q_{\mathrm{out}}^2 - R_{\mathrm{long}}^2 q_{\mathrm{long}}^2\right)$$

R_{long} = Longitudinal HBT radius
R_{side} = Transverse HBT radius
$R_{\mathrm{out}} = R_{\mathrm{side}}$ + particle emission duration

- Assumption of Gaussian S(r)
- Ad hoc Coulomb correction
- Results are relatively stable with relatively small statistics
- Still good for systematic studies

New tech

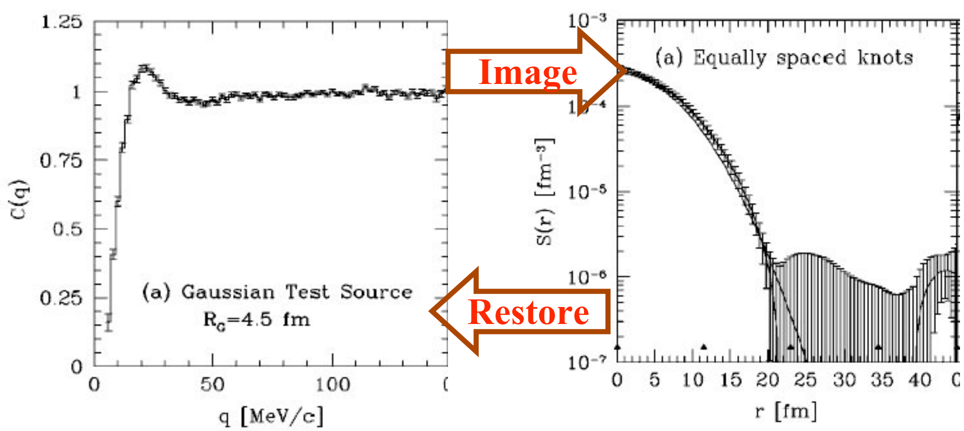
$$R_{\vec{\mathrm{P}}}^{\mathrm{obs}}(\vec{\mathrm{q}}) \equiv C_{\vec{\mathrm{P}}}^{\mathrm{obs}}(\vec{\mathrm{q}}) - 1 = \int d\vec{\mathrm{r}} K(\vec{\mathrm{q}},\vec{\mathrm{r}}) S_{\vec{\mathrm{P}}}(\vec{\mathrm{r}})$$

$$K(\vec{\mathrm{q}},\vec{\mathrm{r}}) = \left|\Phi_{\vec{\mathrm{q}}}(\vec{\mathrm{r}})\right|^2 - 1$$

is kernel which can be calculated from BEC and known final state interactions of pairs.

$$S_{\vec{\mathrm{P}}}(\vec{\mathrm{r}})$$

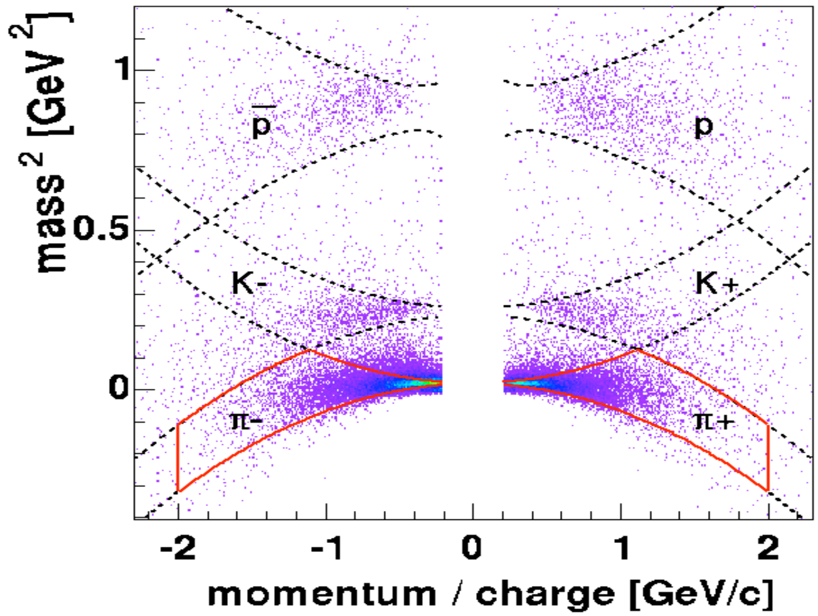
is source function which represents the emission probability of pairs at r in the pair CM frame.

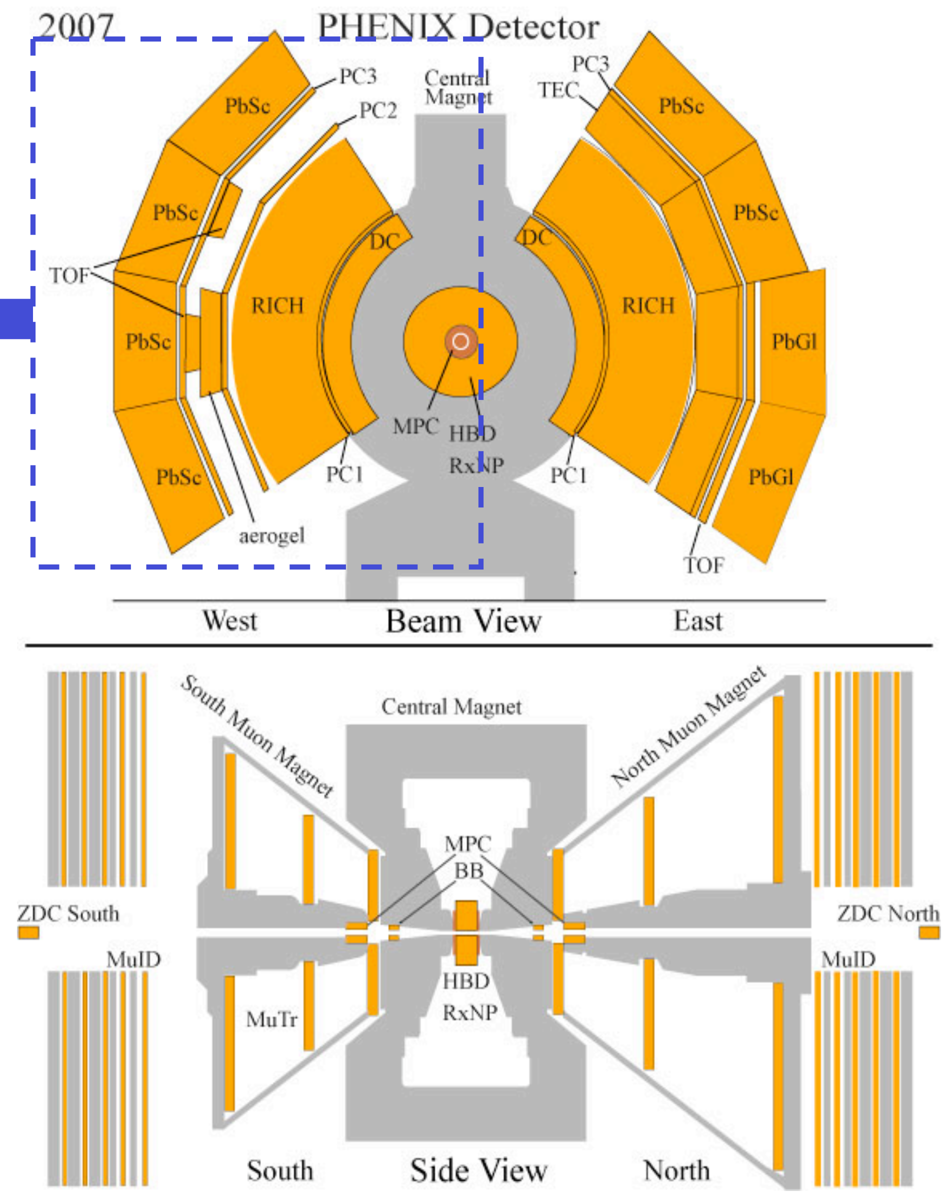


- Model independent
- Accurate treatment of Coulomb effect
- Sensitive to higher r (small q) region
  --> Close to the detector resolution
- Need a lot of statistics

Hadron PID by PHENIX detector

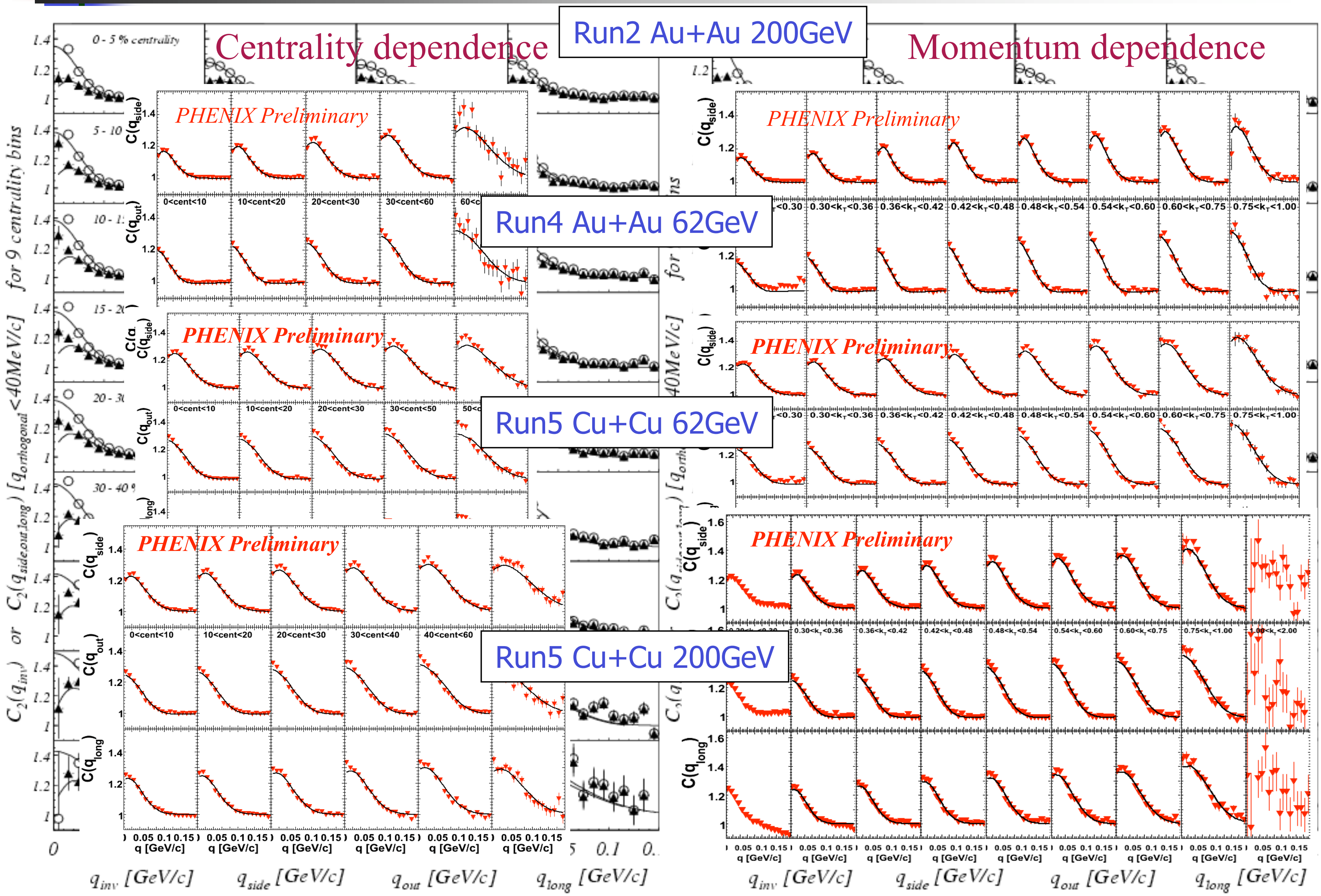
Good pi/K separation p~1.2 GeV/c





Year	Species	$\sqrt{s_{NN}}$	int.Ldt	Ntot
2000	Au+Au	130	1 mb^{-1}	10M
2001/2002	Au+Au	200	24 mb^{-1}	170M
2002/2003	d+Au	200	2.74 nb^{-1}	5.5G
2003/2004	Au+Au	200	241 mb^{-1}	1.5G
	Au+Au	62	9 mb^{-1}	58M
2004/2005	Cu+Cu	200	3 nb^{-1}	8.6G
	Cu+Cu	62	0.19 nb^{-1}	0.4G
	Cu+Cu	22.5	2.7 mb^{-1}	9M

Measured 3-D correlation functions (charged pions)



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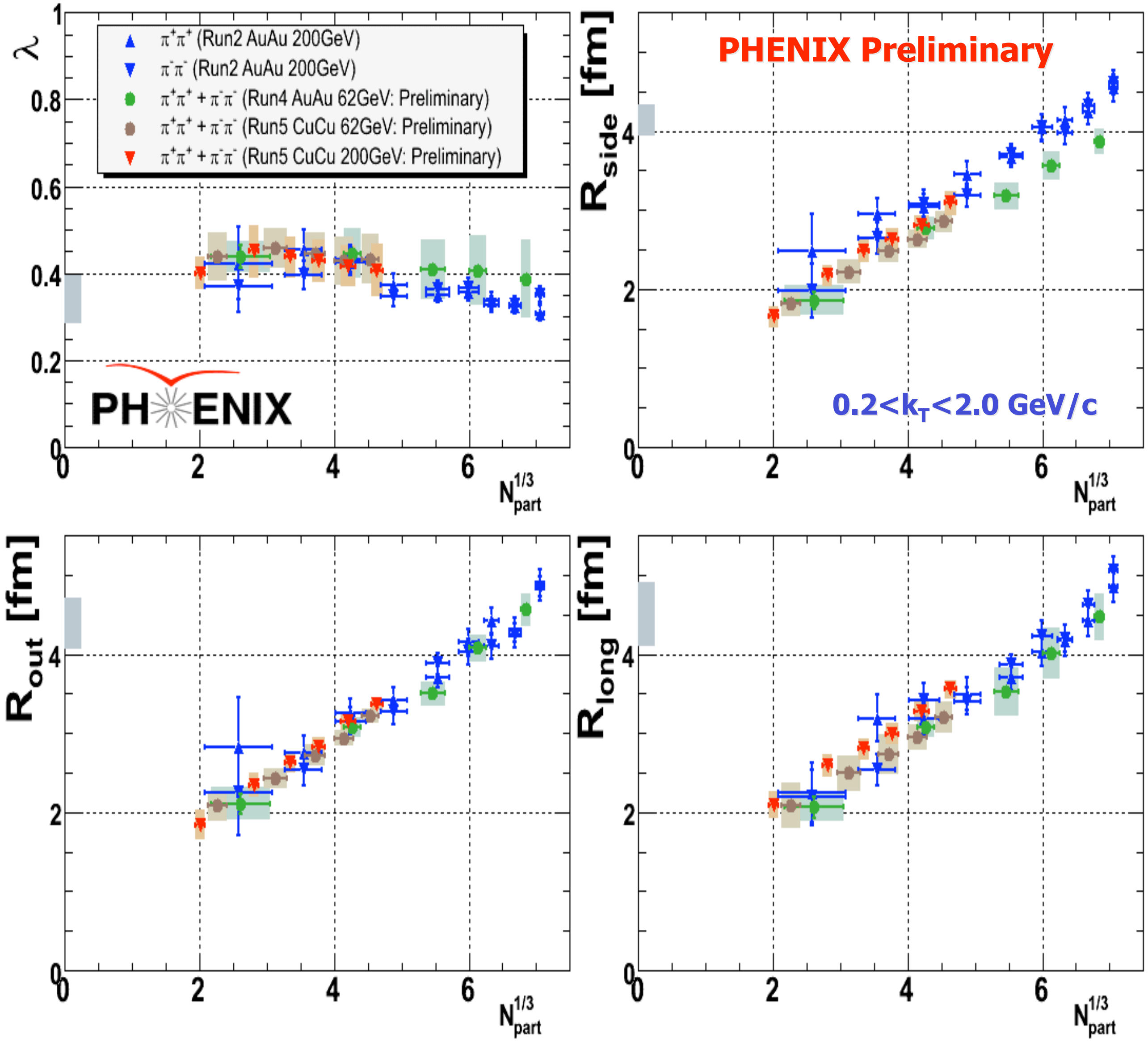
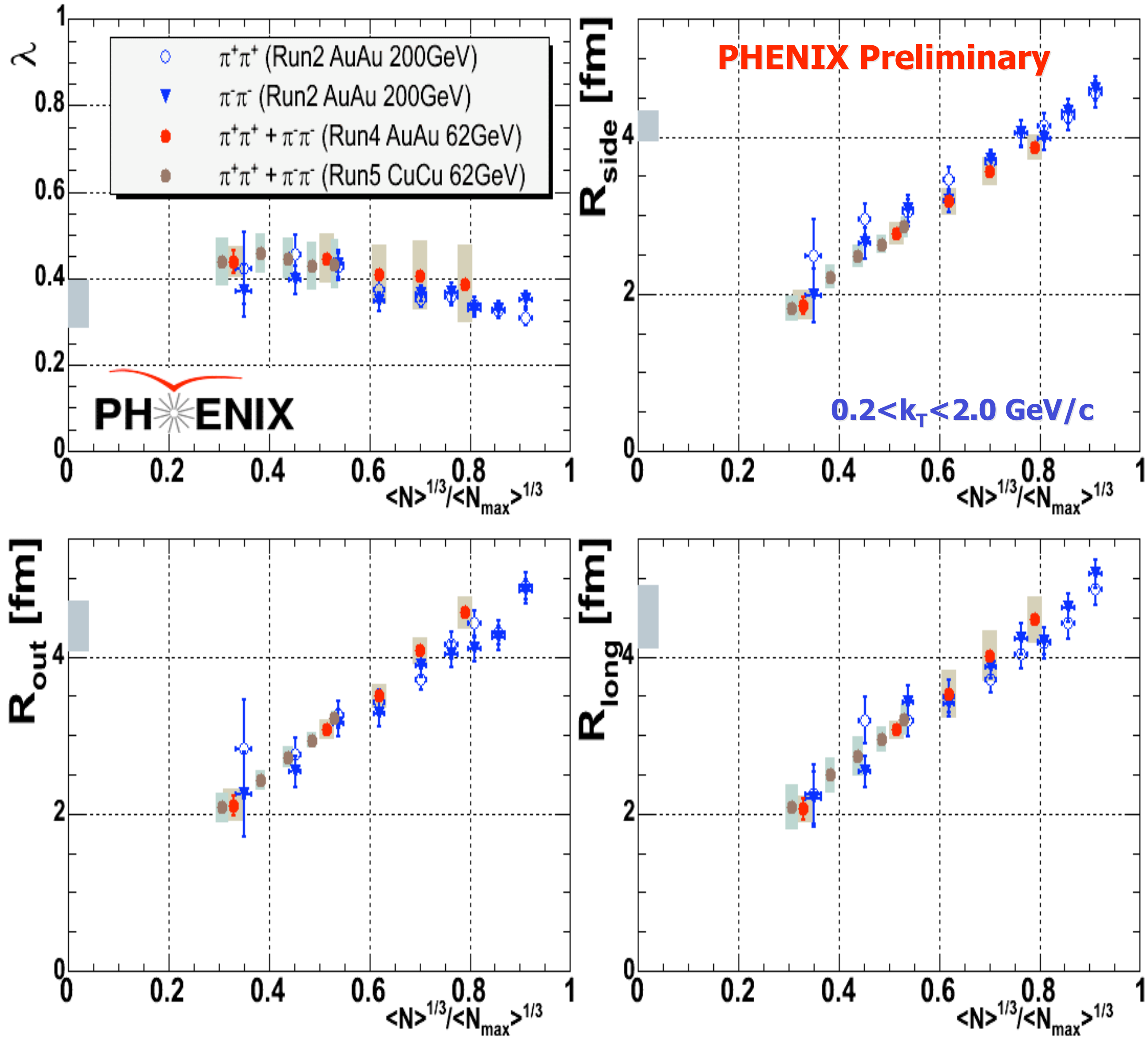
Centrality (N_{part}) dependence of HBT radii



- All HBT radii show linear increase as the cubic root of the number of participants ($N_{part}^{1/3}$).
- Spherically symmetric source $R_{side} \sim R_{out} \sim R_{long}$.
- R_{side} and R_{long} shows a systematic deviation between 200 GeV and 62.4 GeV data sets, while R_{out} are almost consistent between the energy range.

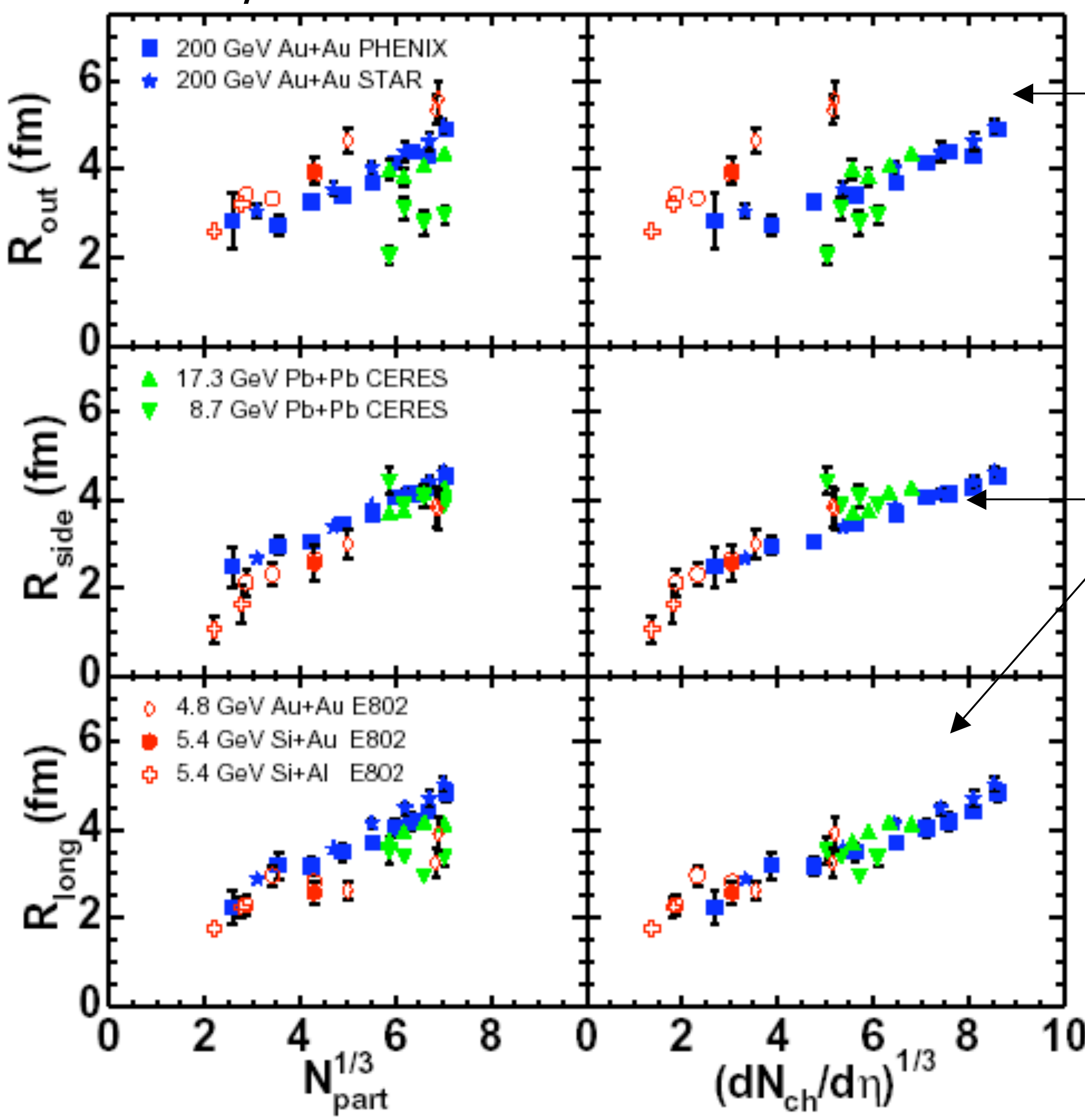
Multiplicity dependence of HBT radii



- All HBT radii show linear increase as the cubic root of track multiplicity ($N^{1/3}$).
- HBT radii extracted from Au+Au/Cu+Cu collisions at 62-200 GeV are consistent with each other at the same track multiplicity.
- Multiplicity is a parameter which determine HBT radii.

Energy scan of multiplicity scaling of HBT radii

M.A. Lisa, S. Pratt, R. Soltz, U. Wiedemann
nucl-ex/0505014



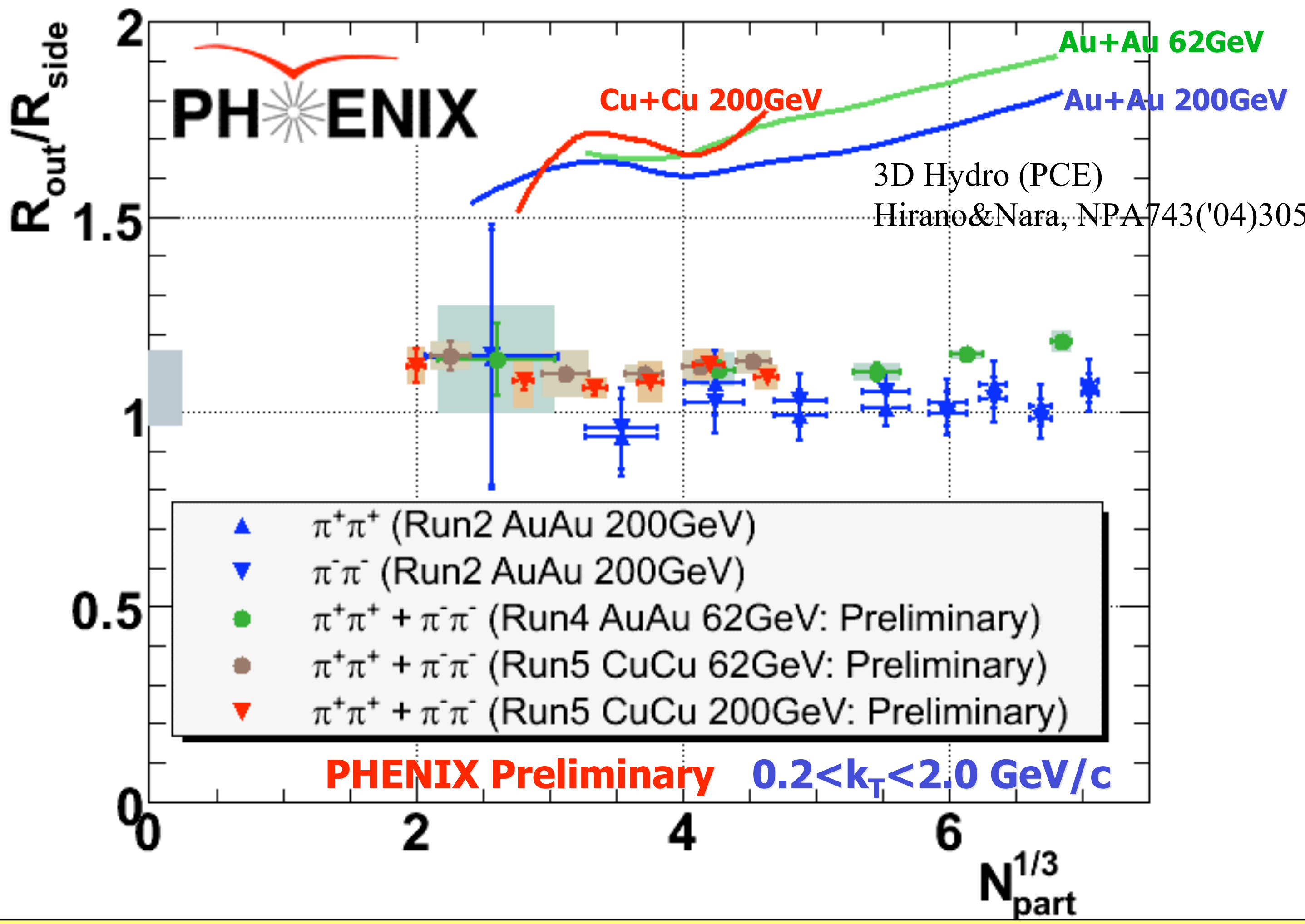
R_{out} is not scaled with $dN/d\eta$ but N_{part} for AGS-RHIC energy?
Or emission duration is significantly changed from AGS to SPS?

R_{side} and R_{long} seem to scale with $dN/d\eta$ rather than N_{part}.

Need detailed study of HBT radii as a function of $dN_{ch}/d\eta$ between AGS-SPS energy region

Interesting to see this scaling holds at LHC.

N_{part} dependence of R_{out}/R_{side} ratio



- *There is no significant centrality dependence of R_{out}/R_{side} .*
- *A hydrodynamics model quantitatively fails to predict R_{out}/R_{side} but qualitatively describes differences between Au+Au/Cu+Cu 62-200GeV.*

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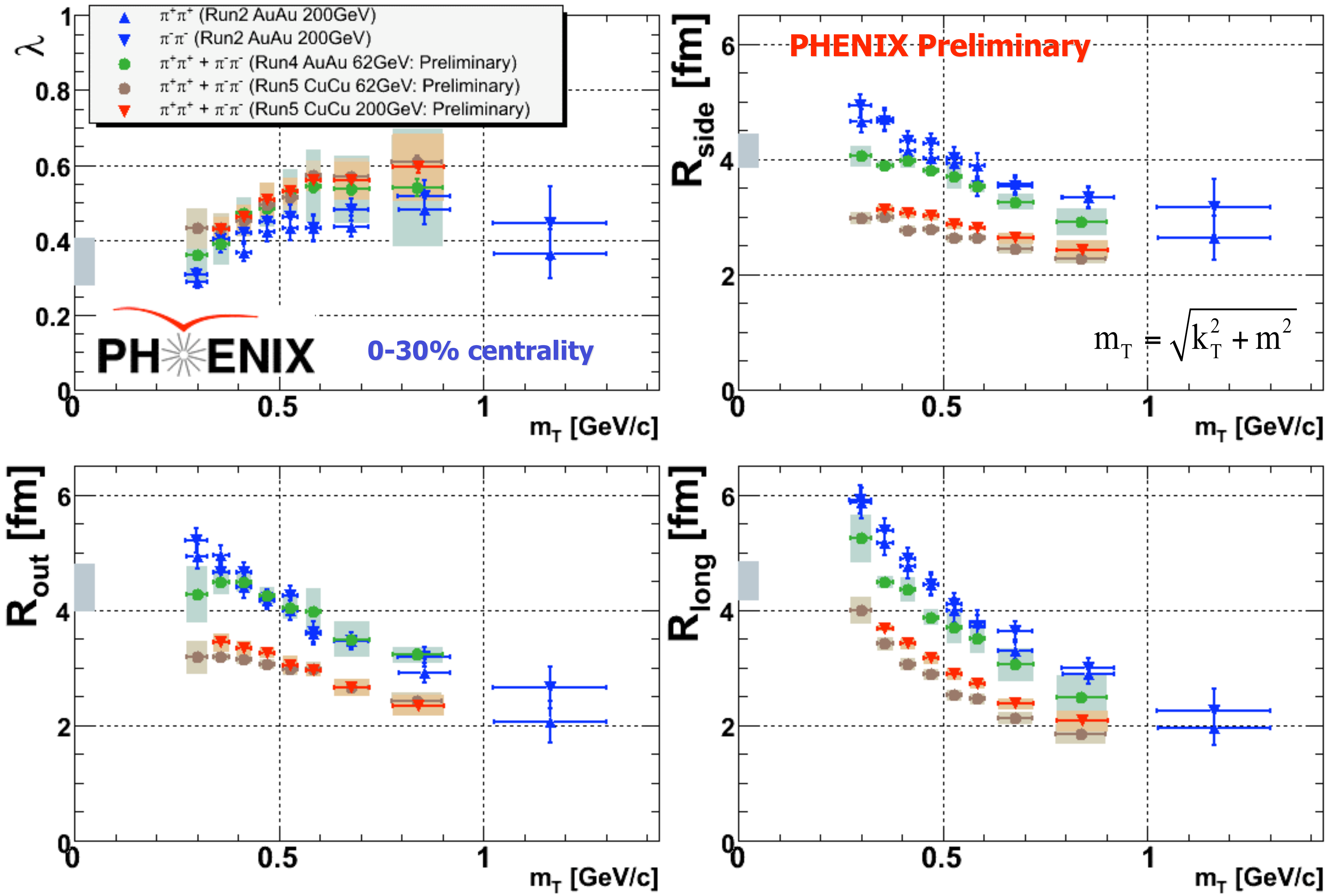
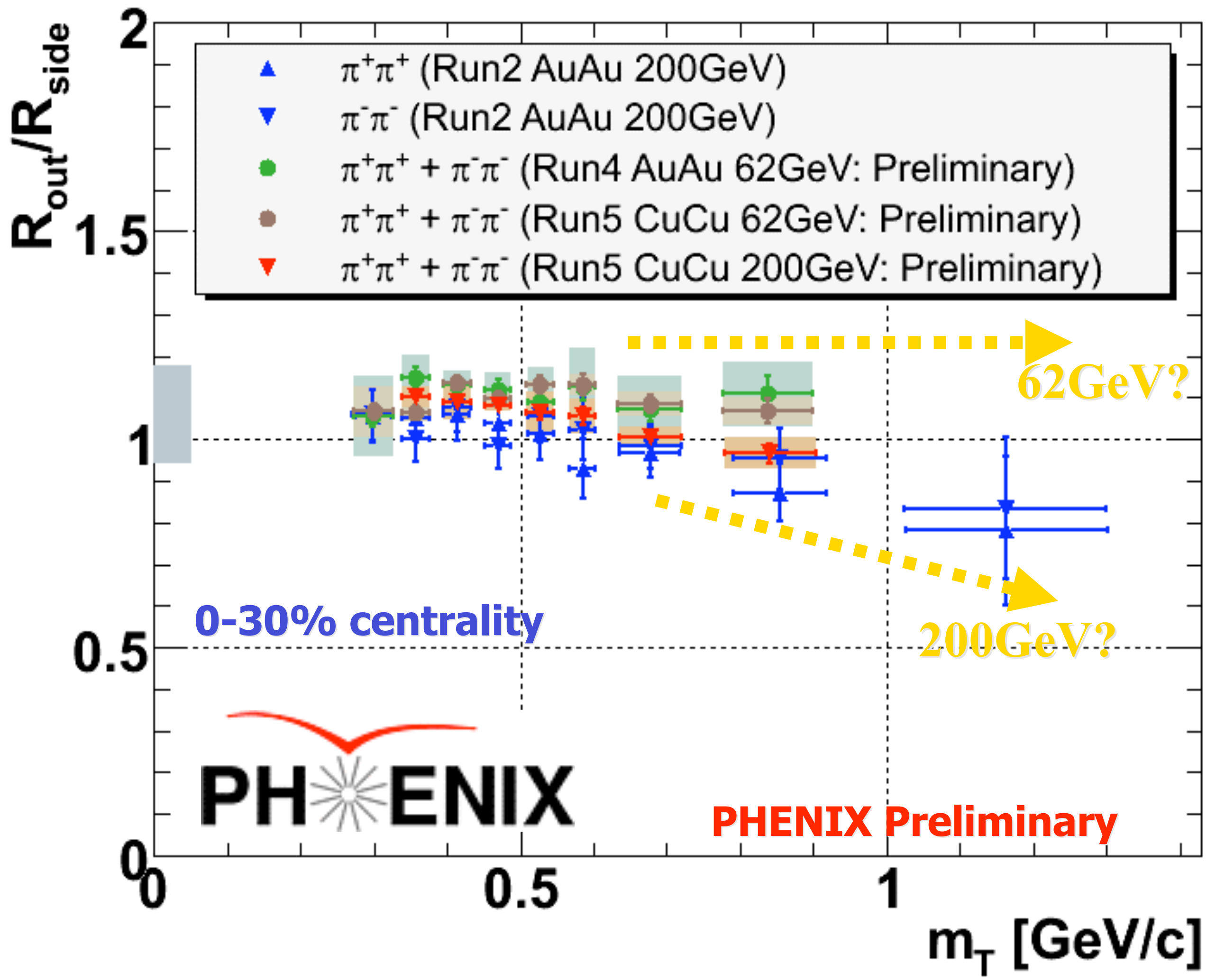
k_T dependence of HBT radii for all data set

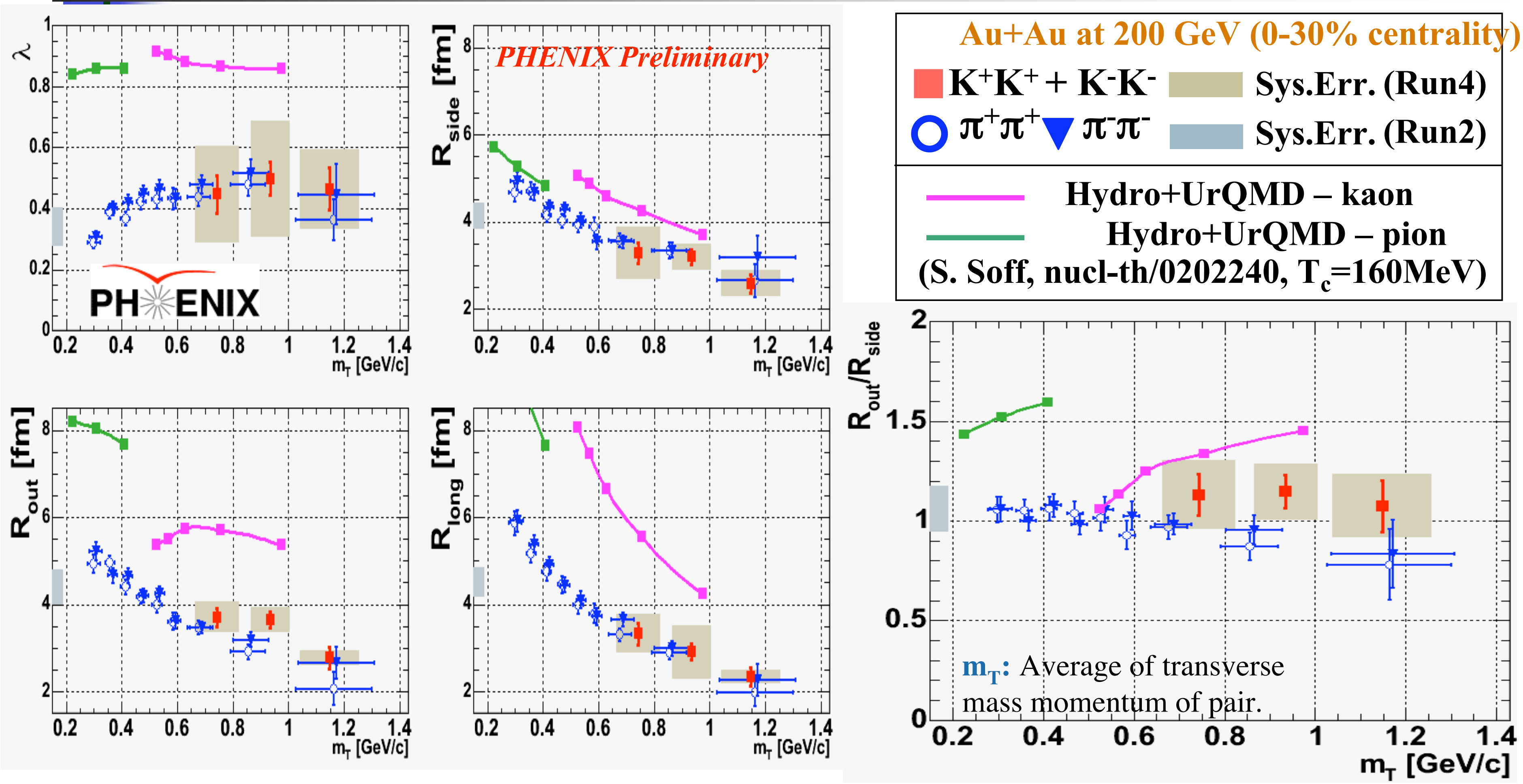


m_T dependence of R_{out}/R_{side} ratio



R_{out}/R_{side} ratio decreases as a function of m_T at 200 GeV but not at 62GeV?
Need further investigation for higher m_T region.

Result of charged kaon HBT radii



- *No significant differences of HBT radii between pion and kaons as a function m_T space-time correlation and freeze-out time between charged pions and kaons.*
- *Comparison with hydrodynamics results hints at small final hadron rescattering effect in Au+Au 200GeV? Or Gaussian HBT radii are insensitive to the effect…*

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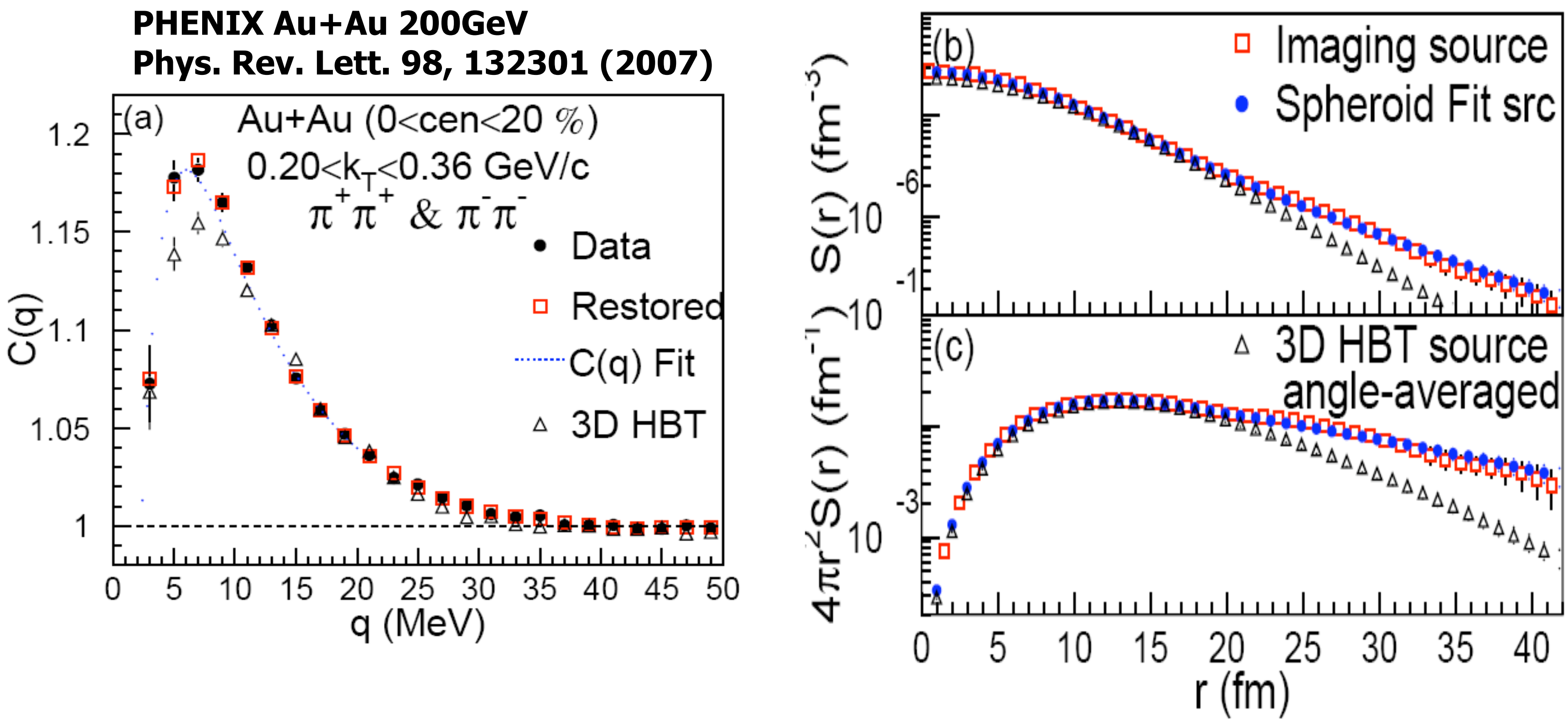
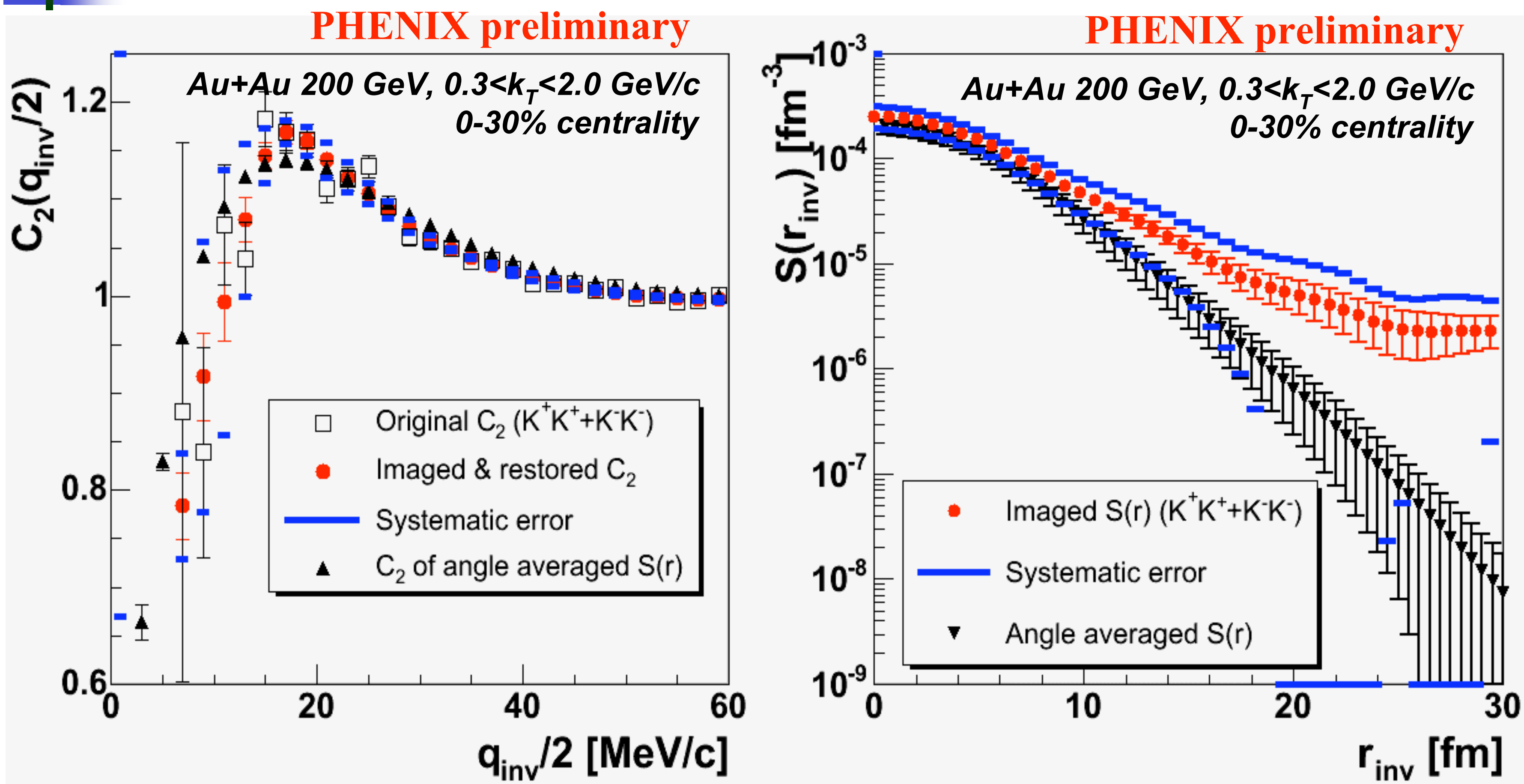
1-D charged pion S(r) in Au+Au at 200 GeV



- The imaged source function deviate from 3-D angle averaged Gaussian source function at > 15-20 fm.
- Where is the non-Gaussian component coming from?
  - **Resonance (omega) effect?, Kinetic effect?, hadron rescattering effect? or life time effect?**

1-D charged kaon S(r) function

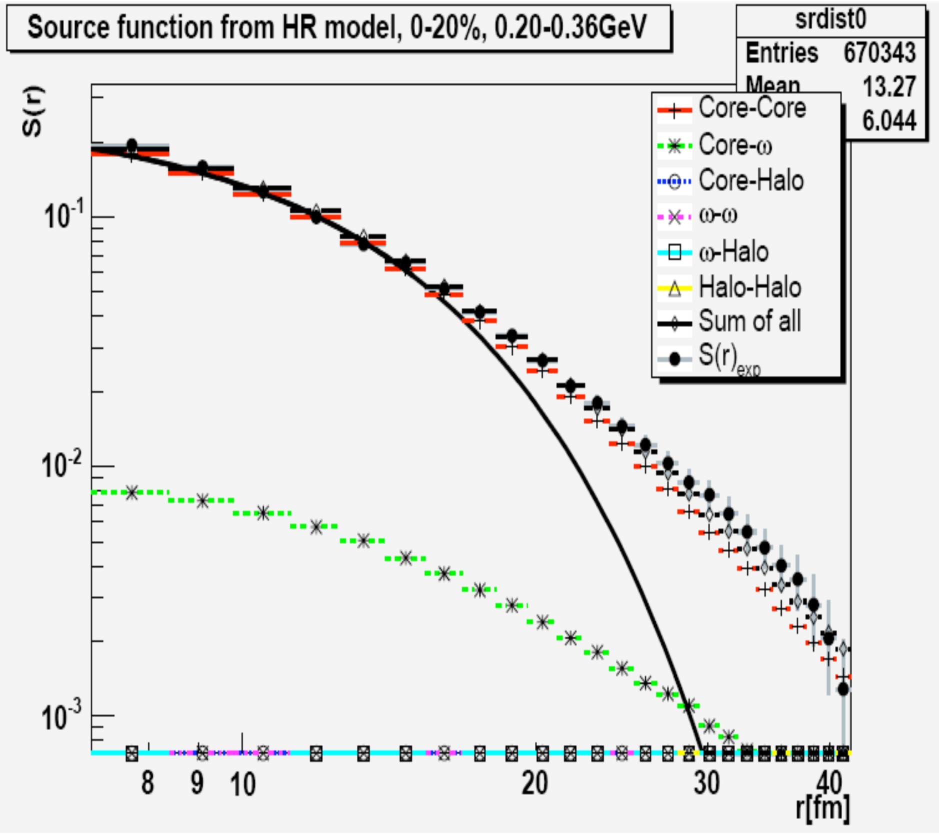


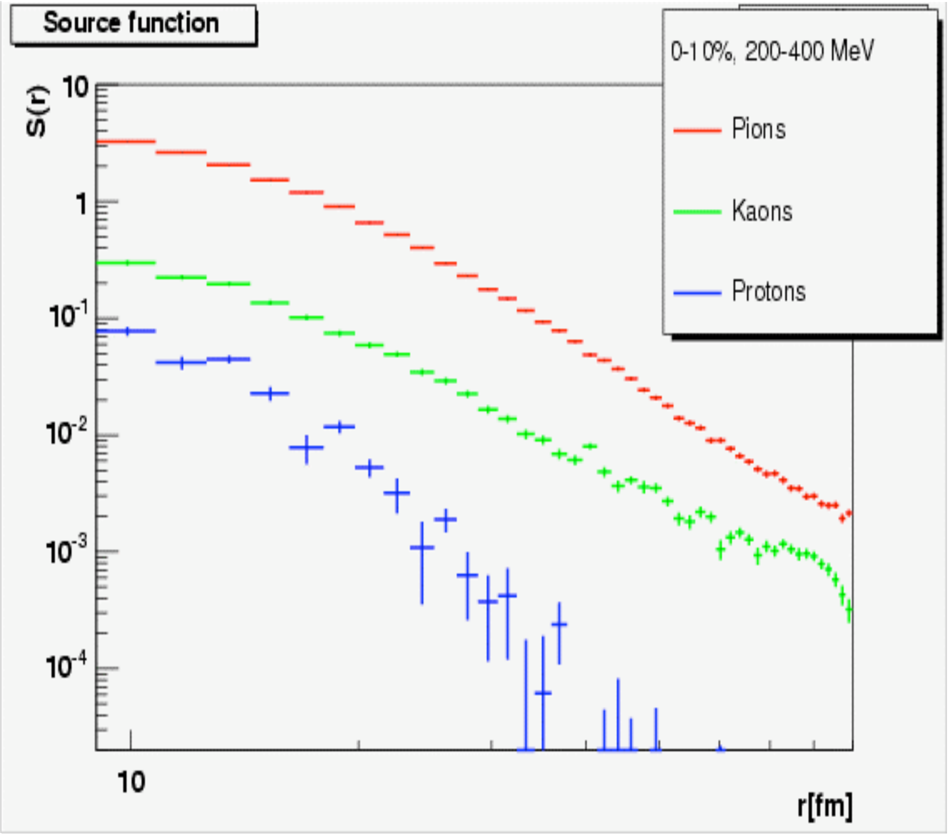
The result might hint at non-Gaussian tail in kaon source function but systematic errors are still too big to conclude and we need to study:

- ***Two track efficiency for real pairs, Zvertex resolution for mixed pairs***
- ***Normalization issue***
- ***Wide k_T binning***

Hadronic Cascade Resonance Prediction of 1D S(r)

M. Csanád, T. Csörgő and M. Nagy, hep-hp/0702032





The tail by HRC reproduce the experimental non-Gaussian structure very well - Levy type distribution.

The tail strongly depends on PID (particle type) in the MC simulation in which largest for kaons - that have the smallest cross sections (i.e largest mean free path).

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Summary

- Centrality dependence of 3-D HBT radii
  - HBT radii linearly increases as a function of $(N_{part})^{1/3 \text{ or}}$ or $(\text{multiplicity})^{1/3}$
  - HBT radii are found to be well scaled with multiplicity rather than N_{part}.
  - There seems to be no significant centrality dependence of R_{out}/R_{side}.
- Momentum dependence of 3-D HBT radii
  - A short emission duration (R_{out}/R_{side}~1) excludes a naïve assumption of 1st order phase transition, and inconsistent with hydrodynamics results.
  - $R_{out}/R_{side}(m_T)$ behaves differently between 62 and 200 GeV.
  - pi/K HBT radii are well scaled with m_T (small hadron rescattering effect?)
- Detailed source structure by HBT-imaging analysis
  - Charged pion show non-Gaussian structure at large r region.
  - Need to stabilize kaon imaging to study PID dependence of S(r).
  - Particles carry the information of mission duration, hadron rescattering effect, etc away of usual HBT radii and can only be observed at large-r region by imaging analysis.

Thanks!

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*as of March 2005